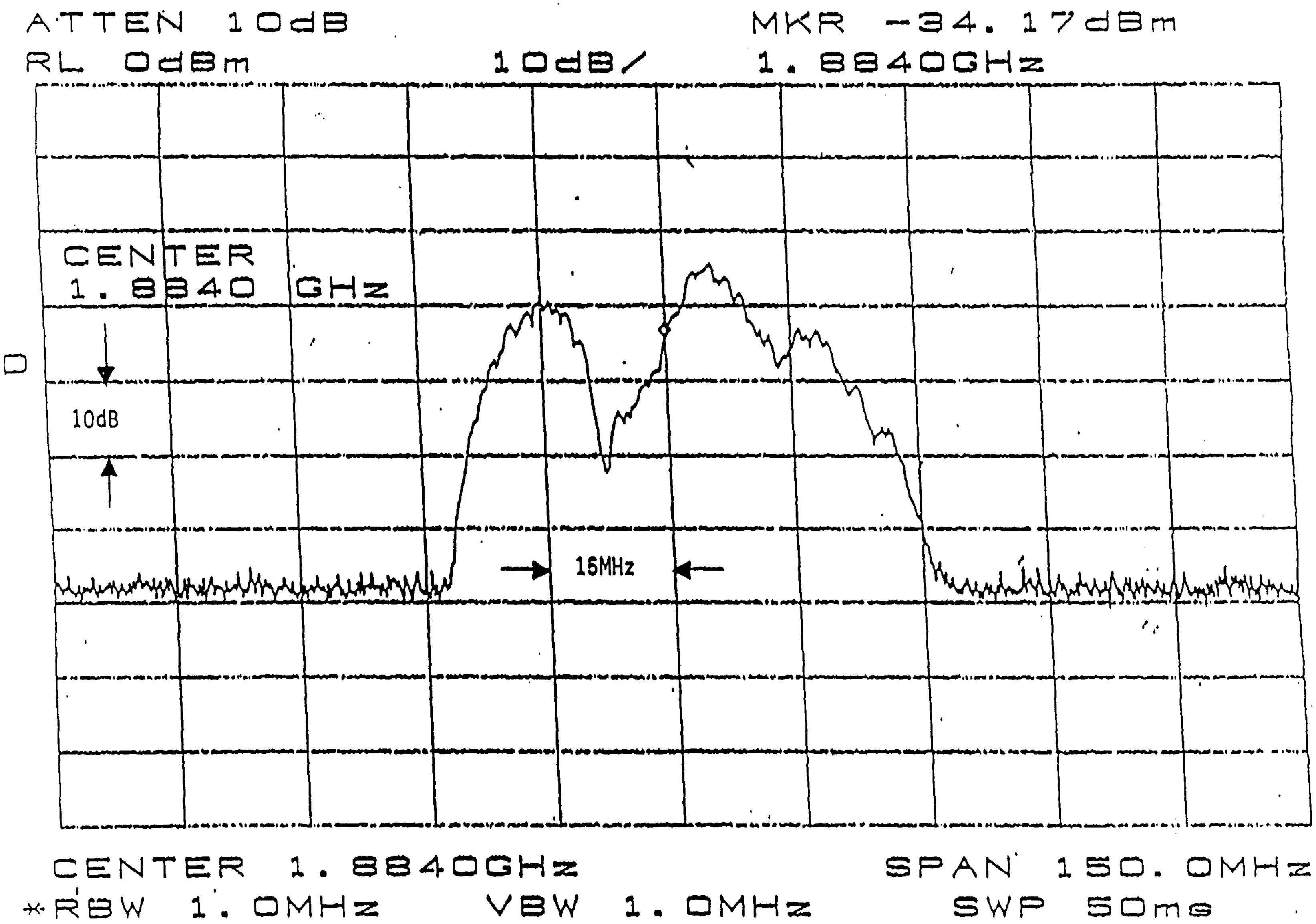
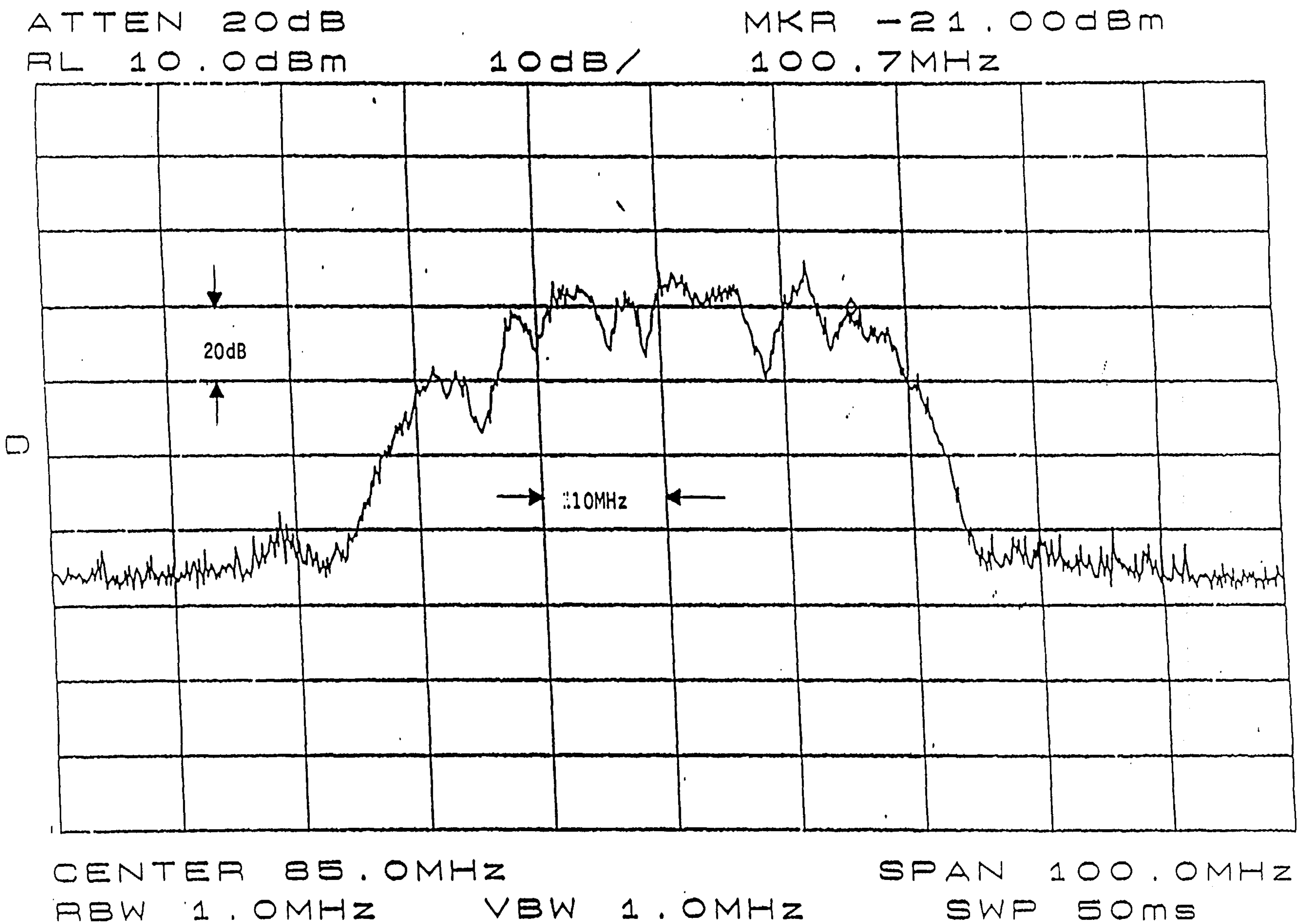



Variation Of Voltage With Frequency When There Is Significant Fading Due To Multipath Propagation

**FIGURE A.2.a**

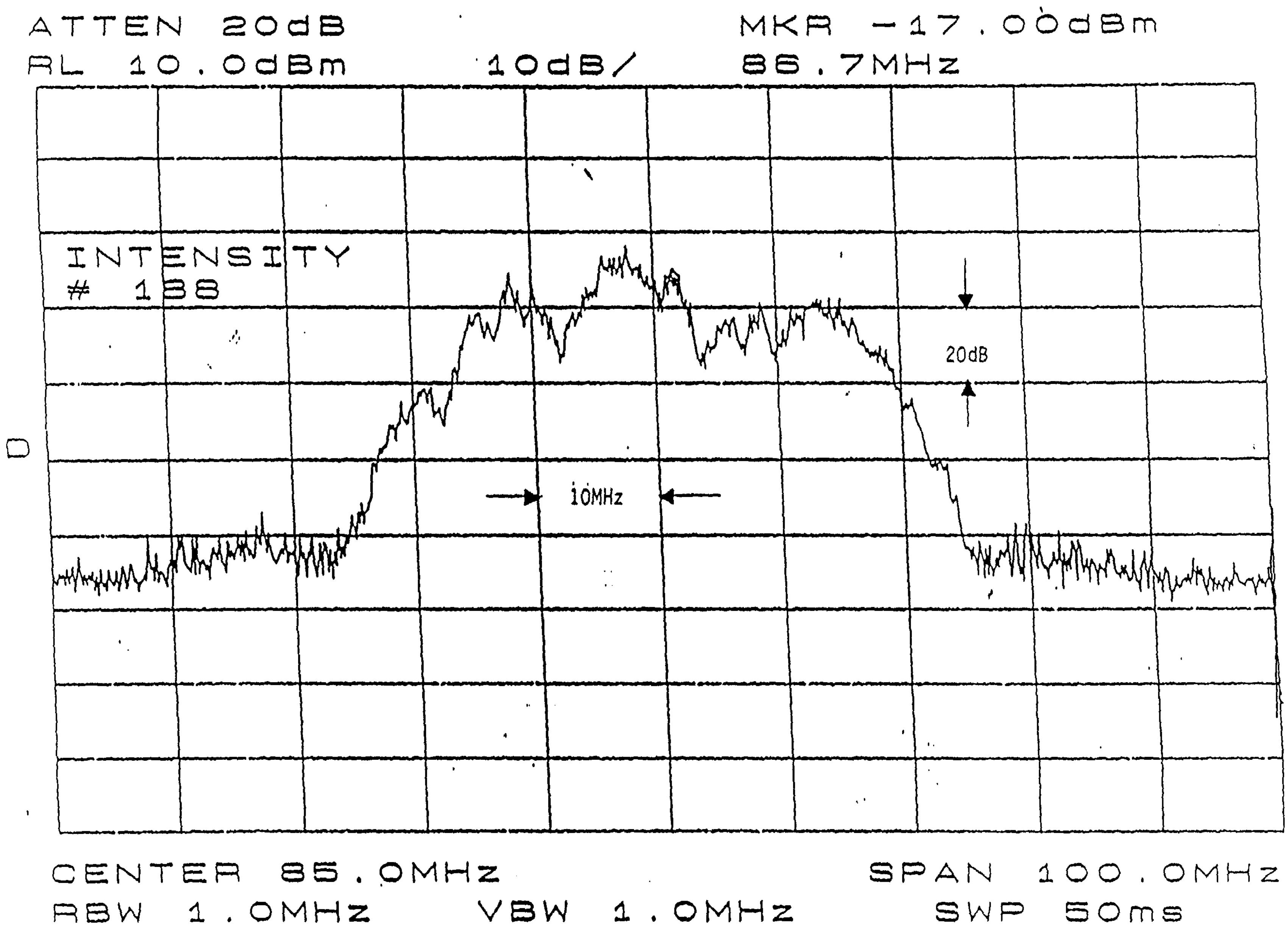
SCS Office




Spectrum Analyzer Plot Handset #2, Site #2; Receiver Monitor Port

**FIGURE A.2.b**

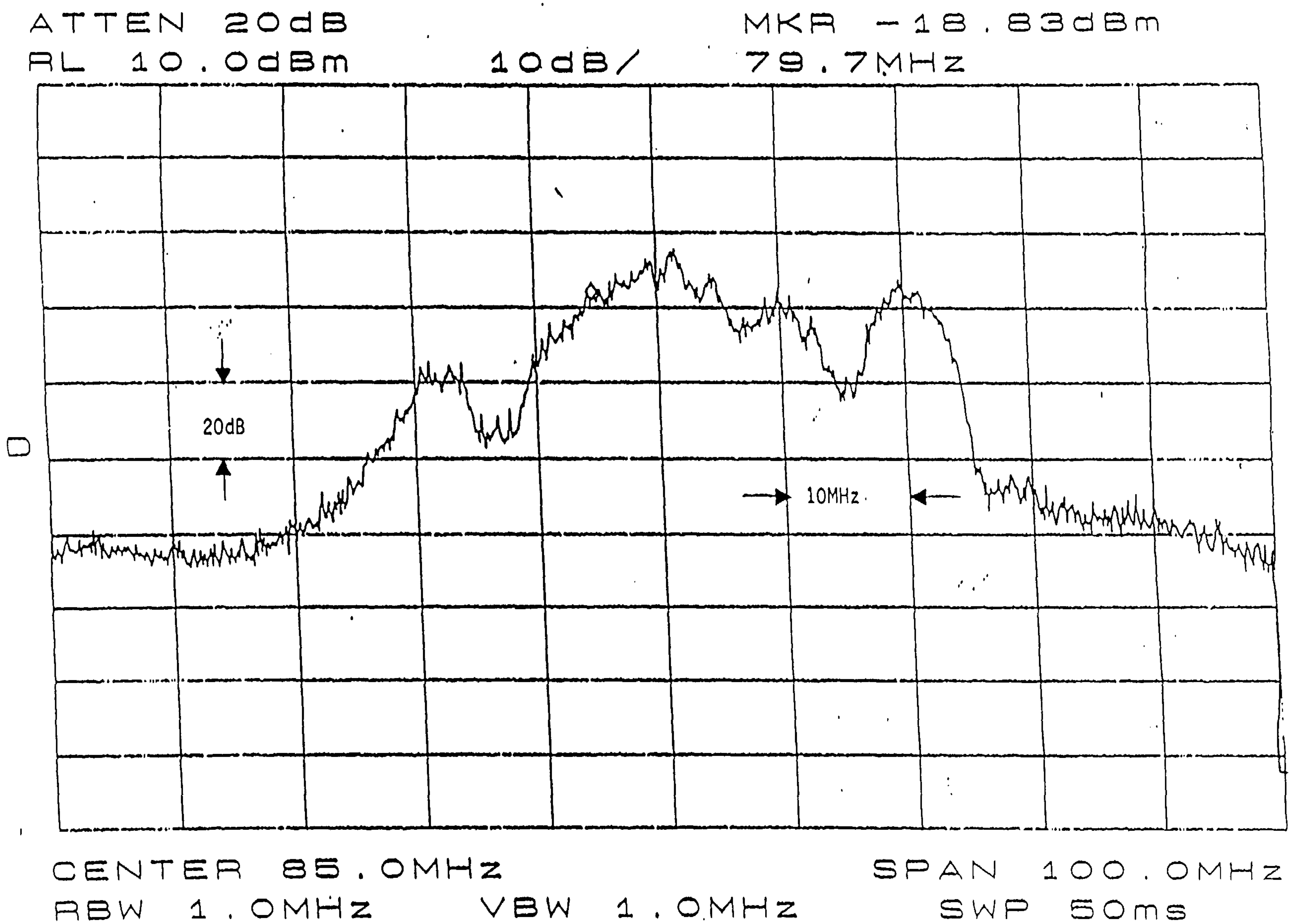
Pedestrian Mall WTC & WFC




Spectrum Analyzer Plot; Site #6, Receiver RF Monitor

**FIGURE A.2.c**

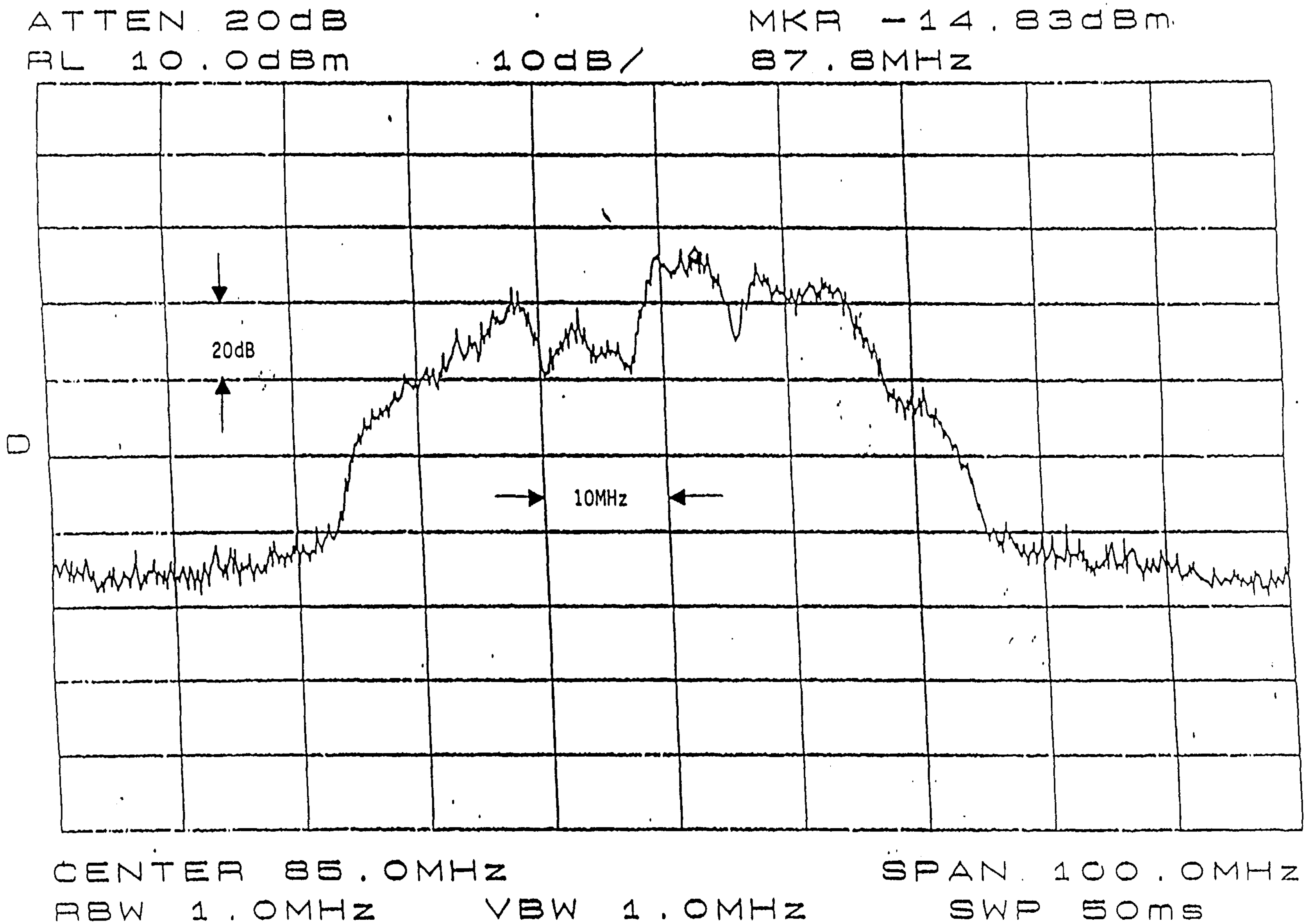
Courtyard of the WTC




Spectrum Analyzer Plot; Handset #2, Site #3, Receiver Monitor Port

**FIGURE A.2.d**

Indoor in the Offices of a Major Investment Banker




Spectrum Analyzer Plot; Handset #2, Site #8, Receiver Monitor Port

**FIGURE A.2.e**

Indoor in the Eye & Ear Infirmary

## APPENDIX B

### Broadband-CDMA vs Narrowband Technologies

The significance of fading due to multipath propagation is that the resulting received signal power of a faded signal is often less than what is required for satisfactory communications. For example, if a received signal is 100 picowatts (-70dBm) when there is no fading and 1 picowatt (-90dBm) after fading, then that loss of 100 (20dB) due to fading will severely impact the quality of communication.

In order to insure that the loss of quality due to fading caused by multipath propagation is minimized, a broadband CDMA system was designed. This B-CDMA℠ system spreads the signal's bandwidth from an information bandwidth of 32kHz to the spread spectrum bandwidth of 48 MHz. Since the observed fading due to multipath is usually less than 10 MHz, the power loss of the B-CDMA system due to the "worst-case" observed fading is approximately 2dB. In contrast, a narrowband signal, say one which has a bandwidth of 1 MHz, whether it be FDMA, TDMA or CDMA, will suffer fades exceeding 10 to 30 dB.

Other technologies proposed for use in the 1850-1990 MHz band include FDMA, TDMA and CDMA, each using 1 MHz of bandwidth. Using such narrowband technologies will result in severe degradation of quality as a result of the deep (more than 10dB) broadband fades encountered. For, in these systems, the assigned frequency band could readily fall into a spectral null (see Figs. A.2). In an attempt to insure that this does not deteriorate the quality of the transmission, the transmitted power must be increased 10 to 30dB, or more, and spatial and/or time diversity employed. Still, as we all are aware, the current FDMA cellular systems suffer from severe fading.

## APPENDIX C

### B-CDMA Provides the High Efficiency Needed

In order to obtain a relationship between the number of users/cell as a function of the processing gain we first define the following parameters:

$P_R$ = Desired Power Received, mW

$P_I$ = Interference Power Received, mW

I = Post-Despread Interference Power

= $P_R$/P.G., mW

P.G. = Processing Gain

$P_T$ = Transmitted Power, mW

$G_{BS}$ = Base Station Antenna Gain

$P_L$ = Path Loss

$L_a$ = Additional Line Losses

$P_n$ = Thermal Noise in the Receiver

r = Fraction of Cell Power Interference contributed by Adjacent Cells in Cellular System (typically r=0.6)

v = Voice Activity factor (v = 2 if voice activity detection is employed)

N = Number of Users/Cell

We can now write

$$P_R = \frac{P_T\, G_{BS}}{(P_L) \cdot L_a} \tag{C.1}$$

and

$$I = [P_n + (\frac{1+r}{v})\ (\frac{N}{3})\ P_R\ ] \cdot \frac{1}{P.G.} \tag{C.2}$$

Thus, $P_R/I$ (which is also the "equivalent $E_bN_o$") is

$$\frac{P_R}{I} = \frac{P_R}{P_n + (\frac{1+r}{v})\ (\frac{N}{3})\ P_R} \cdot (P.G.) \tag{C.3}$$

In order to guarantee a given performance, $P_R/I$ is specified by a quality factor Q. Then (C.3) becomes

$$Q = \frac{P_R}{I} = \frac{P.G.}{\frac{P_n}{P_R} + (\frac{1+r}{v})\ (\frac{N}{3})} \tag{C.4}$$

Substituting $P_R$ from (C.1) into (C.4) gives

$$Q = \frac{P.G.}{P_n \cdot \frac{(P_L) \cdot L_a}{P_T G_{BS}} + (\frac{1+r}{v})\ (\frac{N}{3})} \tag{C.5}$$

Solving for the Transmitted power $P_T$ yields:

$$P_T = \frac{Q\ [P_n \cdot \frac{(P_L) \cdot L_a}{G_{BS}}}{P.G. - (\frac{1+r}{v})\ (\frac{N}{3})\ Q} \tag{C.6}$$

This is a general expression which parameterizes the relationship between $P_T$, N and $P_L$, which, in turn, is dependent on distance, d.

In any given application, the parameters, Q, $P_n$, P.G., $L_a$, r, v and $G_{BS}$ are specified.

Referring to (C.6) we note that the maximum number of simultaneously active users/cell, $N_{max}$, that could be achieved <u>regardless of cell size</u> is,

$$N_{max} - P.G.(3/Q)\ v/(1+r) \qquad \text{(C.7)}$$

users/cell. At this point, the transmitter power required becomes infinite. This phenomenon represents the complete saturation of the CDMA system by its <u>own</u> interference, and increasing each user's power will only generate more self-interference.

For data communication using forward error correction (FEC), assume a maximum undecoded bit error rate of $10^{-2}$, which corresponds to a quality factor Q=2.5. Letting v=1 (voice activity detection cannot be used) and r=0.6, which assumes that the interference due to users in adjacent channels is equivalent to increasing the number of users in the cell by 60%, yields the maximum number of users,

$$N_{max} - 0.75PG$$

Since this value requires an infinite transmitting power, the actual number of users in a B-

CDMA cellular system is typically limited to a value $N \approx 0.5N_{max}$[1]

Thus, for a PCS system using B-CDMA, with a chip rate of 24Mchips/s and a bit rate of 144kb/s to achieve each user operating at an ISDN rate, the processing gain P.G. = 166 and N=62 ISDN users per cell.

For voice communication, the maximum number of users $N_{max}$ is found from (C.7) by letting v=2 to allow voice activity detection, r=0.6, and Q=2.5. The processing gain is 750 for high quality, 32kb/s voice transmission. Thus, for voice

$$N_{max} \approx 1.5PG \approx 1125$$

Since this value requires an infinite transmitting power, the actual number of simultaneous voice users in a B-CDMA cellular system is typically limited to

$$N \approx 0.5N_{max} \approx 560 \ users/cell$$

The above results ignore antenna segmentation which can be used to increase the number of users/cell.

Note that if the bandwidth is decreased by decreasing the chip rate, the processing gain will decrease, the number of dropped calls due to fading will increase and the number of users/cell must be decreased proportionally.

---

[1]The choice of $N=0.5N_{max}$, is chosen so that the maximum transmitter power, given by (C.6) under fully loaded conditions ($N=0.5N_{max}$), is only 3dB greater than the required transmitter power under no-load (N=1) conditions.

## APPENDIX D

Experimental Results to Demonstrate Coexistence

To demonstrate the ability of the B-CDMA system to insure coexistence, measurements were taken of the power needed for PCS handsets to reach the "Threshold" of the microwave receiver, following Document 10E. Working with the fixed service microwave users in Houston and Orlando, the microwave system was adjusted as required by Document 10E. During the Field Tests the PCS handset simulator's power required for Threshold was recorded. These data points were taken at different distances from the antenna and also at different angles from the antenna's boresight.

Two different B-CDMA handset transmitter designs were explored: The first design was a standard design, i.e., the data bandwidth is spread by the PN code, amplified and transmitted. In the second design, the data bandwidth is spread by the PN code, but prior to transmission, power that would ordinarily be transmitted in the frequency band of the point-to-point fixed service microwave user is removed using a filter, called a notch filter[1], which is designed for that purpose. Figure D.1 illustrates the effect of the notch filter on the transmitted spectrum.

The details of these experiments are summarized in [2]. Figure D.2 typifies the results of

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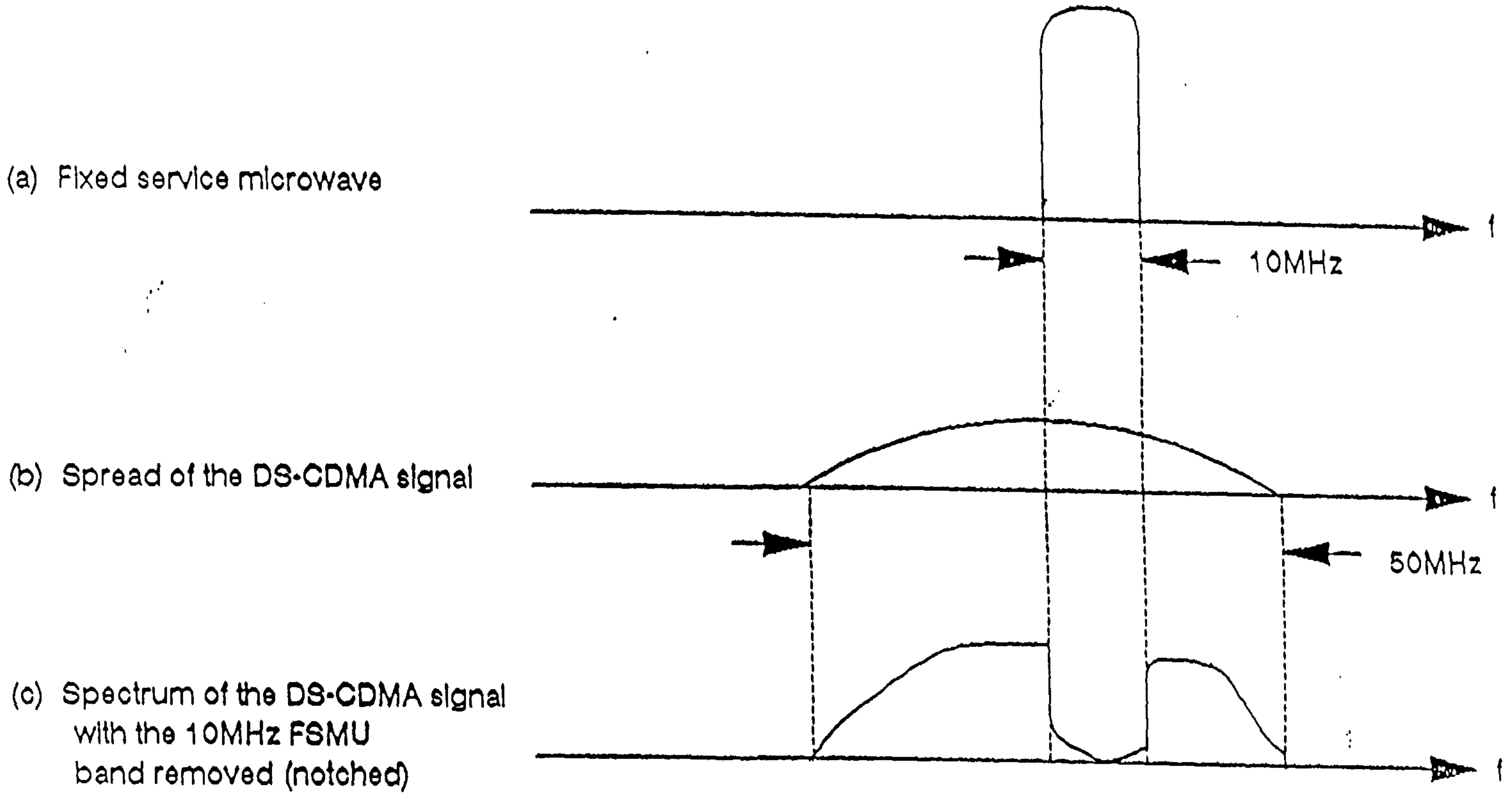
[1]This design is a result of noting that in military systems a notch filter is often used in a spread spectrum receiver to remove a jammer's received power. The effect to the receiver in either case is minimal.




Illustrating The Effect Of The Notch Filer On The Transmitted Spectrum

**FIGURE D.1**

these field tests. In Orlando it was found that without a notch filter 80% of the "universal" interference (as defined by 10E) produced by PCS users on a particular fixed microwave receiver (designated for test by the local users group) was located in a 20 degree sector extending to 1400 feet from the base of the antenna. This represents an area of approximately 0.25 cells. If an adaptive notch filter is employed by users in this sector, the number of PCS users can increase significantly.

Figure D.3 shows the number of users that can coexist with microwave users in suburban areas, such as Houston (the tests were performed in the suburbs of Houston) and Orlando, and in densely populated urban areas such as the Wall Street area of New York. Note that in suburban areas, more than 2000 PCS users/sq. mile can coexist with the microwave users while in New York, due to shadowing effects cause by the high buildings, more than 12,000 PCS users/sq. mile can coexist with the microwave users[2]. If the microwave users were <u>not</u> present, more than 67,000 PCS users/sq. mile could be serviced[3].

While the increase in the maximum number of users if coexistence is not required is dramatic, it is expected to take several years before the user density increases to 12,000 PCS users/square mile. Thus, a gradual transition period exists, unless the fixed microwave users adopt the B-CDMA microwave system.

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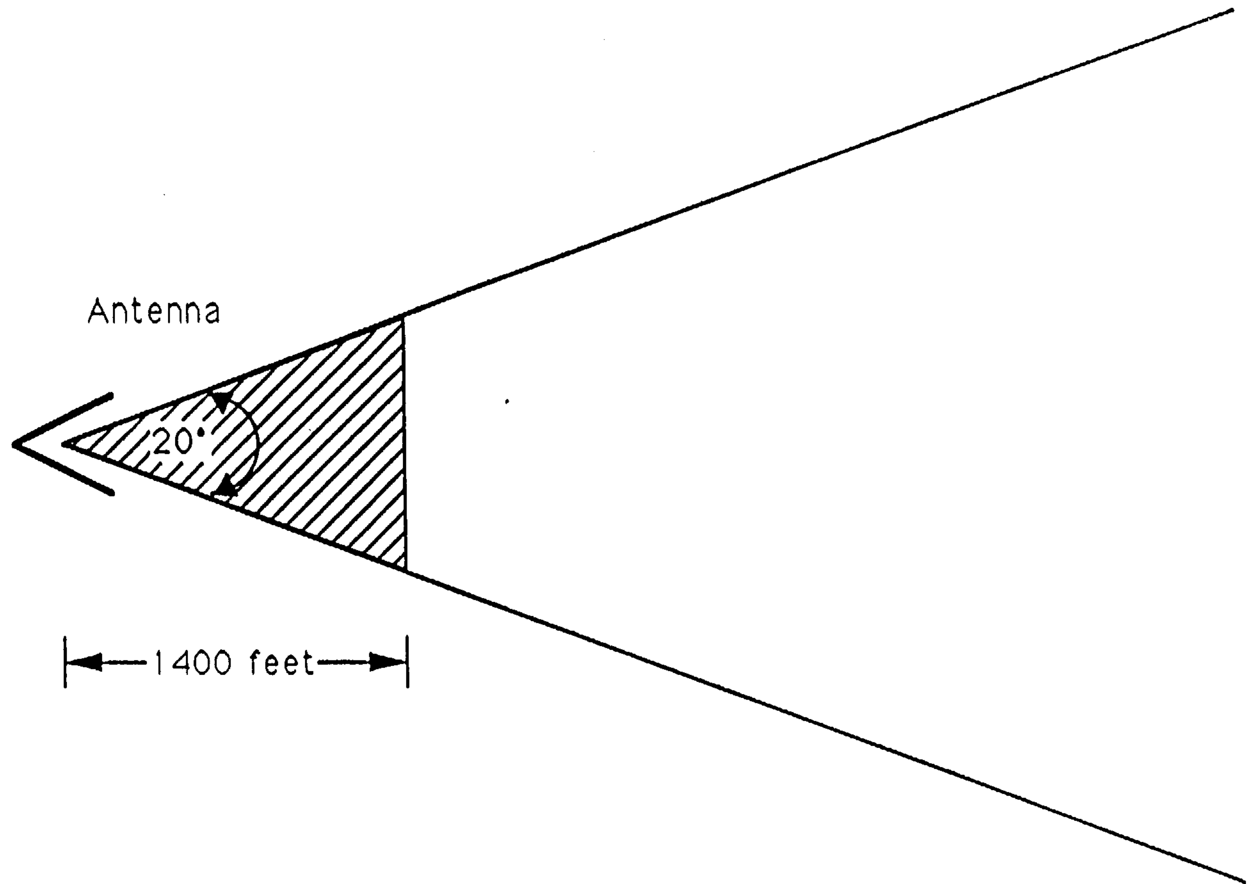
[2]These results assume that cells are separated by 1200 feet.

[3]See Appendix E.




Showing That In The Orlando Field Test, Using An Analog FSM System , 80% Of The Interference Is Produced By PCN Users Located In An Area Of Approximately 0.25 Cells

**FIGURE D.2**

| | Notch Filter & Voice Activity Detection | |
|---|---|---|
| | Number of Users/Cell | User Density (users/sq. mile) |
| HOUSTON | 108 | 2,160 |
| ORLANDO | 126 | 2,520 |
| NEW YORK CITY | 616 | 12,320 |

User Density Per Cell

**FIGURE D.3**

## APPENDIX E

Fixed Service Microwave Users Use Only 1% of the PCS System Capacity

A high data rate fixed microwave system operating at 43 Mb/s uses 64-QAM and operates in a 10 MHz bandwidth.

A PCS system uses 32kb/s. Using QPSK and B-CDMA, each user transmits 64kb/s. Therefore, a 43Mb/s fixed microwave user is equivalent to 43M/64k = 672 PCS users.

Referring to Appendix C we note that there are 560 PCS users/cell. Assuming a 6 sectored antenna, this number increases to 560 x 6 = 3360 PCS users/cell. If each cell is 1200 feet x 1200 feet or 1/20 of a square mile, there are 3360 x 20 = 67,200 PCS users/squire mile.

If we now assume that on the average there is 1 user/square mile, the microwave user constitutes 1% of the capacity of the PCS system.

# APPENDIX F

## BROADBAND-CDMA CAN PROVIDE THE PERFORMANCE DEMANDED BY TODAY'S USERS

### F.1 B-CDMA Resists Fading and Dropped Cells

The prospective users of PCS require wireline performance with wireless convenience at a reasonable handset cost. Performance means high quality voice, no faded or dropped calls, privacy and high data rate transmission and a high user density to insure reliable "big-city" operation. Using B-CDMA, with a transmitter bandwidth of at least 35 MHz and a receiver bandwidth of at least 35 MHz, permits operation with almost no fading or dropped calls.

Fading is characteristic of wireless communications and results since a transmitted signal diffuses as it travels from transmitter to receiver. As a result, a portion of the transmitted signal's power arrives after being reflected from buildings, the ground, trees, leaves, people, etc. Thus, the transmitted signal takes multiple paths to the receiver and each path arrives, delayed from the others and with a different power. This phenomenon is called multipath propagation and is common to all wireless communication.

A result of multipath propagation is that the composite received signals' power varies, depending on the characteristics of the environment (called the "communication channel") through which the signal has travelled. This variation is called "fading". Furthermore, this communication channel can change completely every one-half wavelength which, at a frequency of about 2 GHz, is 3 inches. The bandwidth of the fade, i.e., the range of frequencies which fade together, almost simultaneously, is called the "coherence bandwidth". If the signal is "narrowband" compared to the coherence bandwidth, the signal's received power can vary dramatically if the transmitter, for example, moves by even 3 inches (assuming a fixed receiver). The amount of this power variation, the fading, can be 40 dB to 60 dB. The coherence bandwidth is inversely proportional to the difference between the time required for the signal travelling along the direct path to reach the receiver and the time required for the multipath signal to reach the receiver. Since electromagnetic waves travel 1ns/foot, multipath signals differing by 40 feet will arrive 40 ns apart, causing a fade with a coherence bandwidth of approximately 25 MHz.

SCS Mobilecom has proven, through extensive testing, that a typical fade bandwidth is 3-4 MHz. Thus, in order to insure reliable communication, SCS recommends the use of at least 35 MHz of bandwidth (a factor of approximately 10 times greater than the coherence bandwidth of the fade [see Appendix A]. In Appendix B it is shown that B-CDMA is approximately 30 dB more resistent to fades than other narrowband technologies.

### F.2 B-CDMA Provides High Quality Voice

B-CDMA uses a high quality adaptive delta modulator operating at 32kb/s rather than a synthetic voice coder. Thus, the voice quality is comparable to that obtained by a wire line telephone even in the presence of high background noise such as found in an airport; with multiple speakers simultaneously talking into a portable speaker phone; and is free of speech anomalies and the 160ms processing delay encountered when using a synthetic voice coder which is typically employed in narrowband TDMA and CDMA systems.

## F.3 B-CDMA Provides the Data Rate Desired

B-CDMA transmits 32kb/s data using a spreading code of 24Mb/s. The ratio, called the Processing Gain, is 750 and is proportional to the number of users who can simultaneously use the B-CDMA PCS channel. The processing gain is also proportional to the order of frequency diversity, which is inherent in a spread spectrum system, and hence proportional to the system's immunity to fading.

It is shown in Appendix C, that the number of 32kb/s data users in a PCS cellular system is approximately 37 percent of the processing gain, i.e.,

$$N \approx 0.37(750) \approx 280 \; users/cell^{(1)}$$

If the data rate was 64kb/s the maximum number of simultaneously active users would decrease to 140 users/cell and if ISDN rates (144kb/s) were used by each user, only 62 simultaneously active users/cell could be accommodated.

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[1]This number assumes a omnidirectional antenna. Using, for example, a 6-segment antenna, the total number of users/cell is 6 x 280 ≈ 1700, 32kb/s data users/cell.

In practice, each user would access (and pay for) the amount of bit rate desired, so that in any cell one would have voice users as well as data users and each data user could transmit at the required data rate. We call this feature "bit rate on demand".

## F.4 Relative Efficiency of B-CDMA

B-CDMA not only allows more users/cell than other technologies but does so in a spectrally efficient way.

Consider the present FDMA-AMPS system. As a result of frequency reuse, neglecting segmented antennas, and assuming 7-frequency reuse, there are only 56 AMPS users allowable/cell. The total (transmit and receive) bandwidth required for these users is 3.6 MHz. Hence the total number of users/cell/MHz is 15. However, to insure that users in one cell do not interfere with users in another (noncontiguous) cell occupying the same frequency band requires a cell spacing of about 4.8 km.

Hence the efficiency of a standard AMPS systems

$$E = 0.65 \ users/km^2/MHz$$

In addition, data rates of only 1200b/s or less can be accommodated.

The efficiency of a B-CDMA system capable of operating without fading and with extremely high quality voice allows more than 500 voice users/cell (see Appendix C) with a cell spacing of 0.36 km, and occupies a (transmit and receiver) bandwidth of 96 MHz. The efficiency now is

$$E \geq 48 \ users/km^2/MHz$$

If we include in our calculation the use of a 6-segment antenna, which increases the number of users by a factor of 6; and allow additional services whose spectra overlap each other by less than 50 percent [7], which increases the total number of users by a factor of 2; the total efficiency becomes

$$E \geq 576 \ users/km^2/MHz$$

If, in addition, poor quality voice using a synthetic voice coder (called a CELP), operating at 13kb/s (with FEC) is employed[2], the efficiency now increases to

$$E \geq 1400 \ users/km^2/MHz$$

## F.5 Summary

The use of Broadband-CDMA can result in high quality voice, no fading or dropped calls, data rate on demand, and the needed capacity to serve the needs of the US users at business, play or in the home. To the best of our knowledge, no other technology can display the combination of capacity and performance that B-CDMA does. The capacity of

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[2]Such coders are proposed for use in narrowband-CDMA and TDMA systems.

the B-CDMA system can be significantly greater than that obtained by AMPS and therefore efficiently utilizes the spectrum.

In addition, as discussed in SCS' comments, this high capacity and high performance can be achieved even while sharing the spectrum with the existing fixed microwave users.